Forecasting Research

Forecasting Research Division
Technical Report No. 62

AUTOMATIC APPLICATION OF OROGRAPHIC CORRECTIONS

by
A.G. Davies

30th September 1993

Meteorological Office
London Road
Bracknell
Berkshire
RG12 2SZ
United Kingdom

AUTOMATIC APPLICATION OF OROGRAPHIC CORRECTIONS

A.G.Davies
Meteorological Office, Bracknell, U.K.

30th September 1993

Abstract

A method of automatically determining and applying orographic corrections is evaluated. The use of mesoscale model output to determine position and amount of orographic corrections proved to be successful. This method will be incorporated into the Nimrod software as part of the automation process. The proposed correction method uses a correction factor dependant on the model relative humidity and wind fields at 810 m. The orographic enhancement is multiplied by a correction factor ranging from 0 for relative humidities of less than 85 %, to 1.5 for relative humidities of 100 %. This correction does in some cases lead to slight over-correcting close to the radar, and some fine tuning may be necessary.

Introduction

The output from the Met Office Mesoscale Model provides the means of automatically determining orographic corrections, for real-time radar data as well as for forecast rain fields. The fundamental part of this study was to see if orographic corrections were selected as well by the mesoscale model output as by the existing 'manual' method. A key factor is wind speed and direction since the orographic correction tables derived by Hill (1983) are averages of orographic enhancement for different wind velocities. Also of importance was the use of a humidity factor, an attempt to link the amount of enhancement to relative humidity (RH) at each pixel. It makes sense to reduce the correction where the RH is close to the (low) RH limit where enhancement can take place, and increase the tabluated correction where the RH is very high. The humidity factor is therefore dependant on model relative humidity. It should be noted that model wind fields are known to be more reliable than the humidity fields.

Thus, the purpose of this study was to evaluate the method of combining a mesoscale model forecast of low level winds and relative humidity with radar actual data, to automate the selection of areas where orographic enhancement occured, and to select the appropriate correction table for each pixel before applying the orographic correction. Of particular importance was the suitability of the model relative humidity fields, as this denoted where air was too dry for orographic enhancement to occur. Also, the adjustment of the orographic correction by a factor dependent on the model-

predicted relative humidity was considered. If successful, this method of automatically calculating and applying orographic enhancement will be incorporated into Nimrod.

0.1 Data evaluation

The question arose as to how to evaluate the magnitude of the orographic corrections derived using the mesoscale model output fields. The accuracy of the orographic corrections could be determined from an analysis of gauge data, but this would take a prohibitive amount of time and resources to achieve. Instead, the yardstick adopted was that of the disenhanced field, the raw radar field with the amount of orographic rain seen from by the radar subtracted from it. The effect of applying orographic corrections that are too large are obvious on the disenhanced image (see section 1.2).

1 Correcting rainfall for orographic enhancement

1.1 Orographic enhancement and selection of cases

To study the application of orographic enhancement, test cases had to be selected. However, what makes a good orographic day, a day when orographic enhancement is widespread ? Maps of rainfall distribution show greater amounts over high ground. In the UK this is mainly in the west, on the track of prevailing onshore moist airflow. One mechanism leading to the increase in rainfall over hills is the forced ascent of this moist air, initiating condensation and release of potential instability (see Hill, 1983). Another is the interaction between an existing upper cloud layer and the cloud formed during ascent, the seeder-feeder mechanism proposed by Bergeron (1965).

The amount of orographic enhancement produced by the latter mechanism is observed to depend on:

1. A seeder rate greater than ≈ 0.5 mm hr^{-1}.
2. The moisture content of the air; high θ_w = more available water.
3. Degree of saturation of upwind air. If unsaturated, less growth is possible in the feeder cloud.
4. Low level wind speeds. Orographic enhancement usually increases with increasing low level ($\approx$900 m) wind speeds.
5. Topography (eg, high hills can cause more forced ascent than low ones).

Generally, the criteria for widespread orographic enhancement (widespread rain and high low-level relative humidities and winds) were met when frontal systems moved across the United Kingdom. Case days for this study were duly selected from a study of synoptic conditions in the Daily Weather Record) and based on the above criteria. Case selection is discussed further in section 2.1.

1.2 Derivation of fields

For the purpose of the study, archived raw radar network data were combined with archived wind and humidity data from the mesoscale model. Restoration of archived raw radar data and mesoscale model output is described in the appendix.

The analysis method is outlined in Sargent (1992). Data from the 36 FRONTIERS orographic enhancement fields for the UK, derived from Hill (1983) and Hill et.al. (1981), are selected on a basis of the U and V components of the mesoscale model wind field at 810 m, which is close to the 900 m level used by Hill (1983) to stratify the tables by wind speed.

The U and V components are used to compute the wind speed and direction at each point in the FRONTIERS 5 km grid. The FRONTIERS system uses one of four wind speeds, i.e., 25, 40, 55 or 70 kn. Providing the mesoscale model relative humidity at a point is greater than 85 % the wind speed is tested to see if it lies within the bands 17-31, 32-46, 47-61 and $>$ 61 kn. Depending on which band, if any, the speed lies in and the direction, the appropriate table of enhancements is accessed to provide the enhancement at that point. This value is then multiplied by a factor dependent on the value of relative humidity.

Other derived fields are now described. The orographic area is that area where the wind speed and direction and relative humidity are great enough for enhancement to take place. This is an important model-derived field which should cover all areas where orographic corrections need to be applied. In FRONTIERS orographic areas are defined by the operator where it is thought necessary.

The amount of enhancement actually seen by the radars is taken into account; each radar has a percentage seen table showing, for each pixel, how much of the orographic enhancement is detected. Brown and Sargent (1987) contains the method of calculation of the percentage seen tables. Percentage seen is mostly dependant on the distance of the pixel from the radar. The amount of orographic rain not seen by the radar is added to the radar data to produce an enhanced image, showing the total rainfall. The amount of orographic enhancement seen is subtracted from each pixel base rainfall rate to produce a disenhanced image, which may be used as the the basis for a forecast.

Some pixels in the disenhanced image may at this point become zero or negative. This is due to the humidity factor, percentage seen value or tabulated orographic correction being too large. For example, over-disenhancement may be due to too big an enhancement being applied due to the the wrong orographic table being chosen. However, the orographic table to use is determined from the model winds, taken to be the most reliable parameter used from the model. This is therefore the least likely cause. The problem is more likely to be in the humidity factor calculation or the percentage seen tables, and is further addressed in section 5.

Humidity fields from three levels (20 m, 355 m and 810 m) are initially used, and the resulting corrections compared to determine the best humidity level to use.

Finally, the mesoscale model cloudbase field was extracted. This field is partially derived from the relative humidity fields, and in some part fills in some information about humidities at other levels in the model, and proved to be useful in some cases in determining frontal boundaries.

1.3 Correction methods based on RH fields

At present, based upon advice from Frank Hill (R.Brown, written communication, 1992) the basic orographic enhancements in FRONTIERS are empirically adjusted according to the 900 m relative humidity. If the relative humidity is less than 90 % the enhancements are divided by a factor of 1.3; if in the range 90 % to 95 % they are not modified, and if greater than 95 % the enhancements are multiplied by 1.3.

Sargent (1992) proposed applying orographic corrections where the model relative humidity was greater than 85 %, but multiplied by a factor that increased linearly from 0 at 85 % relative humidity to 1.5 at 100 % relative humidity.

2 Methodology

Firstly, days where widespread orographic correction was expected to be seen were selected. Then a study was made to determine if, using the model relative humidity and wind speed and direction fields, orographic areas were produced which indeed covered all areas where orographic enhancement was thought to be occurring. Using the 85 % RH threshold, orographic areas were produced using relative humidity fields at different levels, to determine the best level to use.

To evaluate the application of a humidity-based scale factor (the humidity factor) the following procedure was used.

1. For selected cases, a comparison was made of runs using the application of full orographic correction against runs using the humidity factor.
2. Using the humidity factor, part of the orographic correction was applied depending on relative humidity. The humidity factor range was from 0 to x 1.5, a linear correction, for relative humidities greater than 85 %.
3. Disenhanced rain fields produced using the humidity factor and model humidity fields at different levels were compared to find the best level to use.
4. Further cases were selected, processed, and near surface model data were compared with surface observations and sonde ascents as an accuracy check (although verifying the mesoscale model is not part of this exercise).
5. Other parameters that might be of use were considered (for example, model cloud base height).
6. An attempt was made to determine which of the possible causes of over-correction was most responsible.

2.1 Selection of case days

Section 1.1 outlined the factors contributing to orographic rainfall. The selection of cases followed the methodology adopted by Hill (1983). Frontal systems lead to a rainfall pattern which is closely allied to the underlying topography, whereas with a day of showers and thunderstorms, the correlation

is usually much less. Hence the fields of orographic enhancement constructed by Hill (1983) were therefore obtained from frontal cases only.

Study of the Daily Weather Records yielded a number of case days where the synoptic situation was conducive to widespread orographic enhancement. Cases were chosen where the passage of a cold frontal system resulted in prolonged, widespread rainfall over areas where orographic enhancement occurs. More often than not these fronts had an associated warm sector with the added possibility of a warm conveyor belt jet adding moisture to the enhancement mechanism.

2.2 Comparison of 'full correction' and 'humidity factor'

The first stage of the analysis was that of comparing disenhancements using the humidity factor with those using the full orographic correction, for humidities greater than 85 %. At the least, it was hoped that there would be little difference between images. At best, it was hoped that the humidity factor would be an improvement.

2.2.1 24APR92 1100 VT: 06 model run (T+5)

There appeared to be little difference between disenhanced images produced using the scaled humidity factor (Fig. 1) and the full orographic correction (Fig. 2), using the model 810 m relative humidity field (Fig. 3); if anything, a few more pixels are over-corrected on the image produced using the humidity scale factor. This is due to the high relative humidity (> 95 %) at 810 m over most of the UK.

2.2.2 03JUL92 1000 VT: 06 model run (T+4)

Like the case of 24APR92, the lowest number of over-corrected pixels occured with the 20 m relative humidity field and using the humidity scale factor. There was little difference between the full-correction and humidity-factor images using the 810 m humidity field. The 20 m field shows what appears to be a rain shadow effect on the Lleyn Peninsula, possibly due to the föne effect.

2.2.3 Summary

Unfortunately, the two cases analysed did not constitute proper tests of the application of the humidity correction factor as the relative humidities were very high, leading to correction factors greater than one at practically every rain pixel. This lead to over-correction. Ideally, relative humidities closer to 85 % were necessary to test the humidity correction factor.

2.3 Evaluation of delineation of orographic areas.

The orographic areas chosen using the 810 m winds and relative humidities at three different levels (20 m, 355 m and 810 m) were evaluated for each case, and were compared with the likely orographic areas determined using synoptic charts (the method used by FRONTIERS operators). Identification of areas where orographic enhancement was likely was aided by the fact that the cases were well-defined frontal systems. This was an important part of the study, as the model had to recognise all

areas where orographic enhancement was occurring. The addition of enhancement where it did not actually occur would also be avoided.

The next step was to further evaluate the degree of disenhancement, using the wind fields at 810 m and relative humidities at different levels. Summaries follow of the analyses of the selected cases, all of widespread frontal rain.

2.3.1 24APR92 1100 VT: 06 model run (T+5)

Figure 4 shows the disenhanced image produced using the 20 m relative humidity field (Fig. 5), using the humidity scale factor. There are fewer over-disenhanced pixels than at 810 m (Fig. 1), but this is partially due to generally lower humidity fields at 20 m. The 20 m field is more indicative of where precipitation may occur, as inferred from the model cloud base field (Fig. 6) which shows a layer of cloud with a low base, associated with the front running north to south across the UK. The model implies, not unreasonably, that the heavy rainfall in S Wales, Cumbria and S and Central Scotland is associated with this low cloud.

2.3.2 03JUL92 1000 VT: 06 model run (T+4)

Figure 7 shows the calculated orographic enhancement using 810 m fields and the scaled humidity factor. Comparison with the humidity fields at 20 m (Fig. 8) and 810 m (Fig. 9) with the raw radar image shows that the 20 m field misses some areas where rainfall is occurring (and therefore where humidity is high). The 810 m > 85 % field covers the whole area where rainfall occurs. Assuming that the orographic corrections are accurate (based, as they are, on model forecast winds which are known to be fairly accurate), comparison between Figure 7 and Figure 8 shows that some areas of orographic enhancement would not detected using the 20 m field. The 20 m data showed a few areas where relative humidity was higher than at 810 m; the only areas where this happened were to the SW and W of Eire, and south of Eire in the Bristol Channel.

2.3.3 11MAY92 2100 VT: 06 model run (T+15)

The raw radar image at this time shows the heaviest rain over south, east and north-west Scotland. The best correlation between actual rainfall location and high (> 85 %) relative humidity was found with the 810 m humidity field, although the high humidity boundary does not extend far enough east from the Scottish east coast. Figure 10 shows the disenhanced image based on the 810 m humidity field. It will be shown later that the large over-disenhanced areas relate to areas of low rainfall, backing up one of the criteria for orographic enhancement laid down in section 1.1 (1), namely, a seeder rate greater than ≈ 0.5 mm hr^{-1}. Also, over disenhancement is more likely in light rain, even for perfect conditions, because of random measurement errors.

2.3.4 12MAY92 0000 VT: 06 model run (T+18)

The greatest orographic enhancement was produced in South and Northwest Wales. The mesoscale model accurately predicted high humidities at 20 m for orographic areas in Wales. At greater than 85 %, the 810 m humidity field covered all areas where there was actual rain (the 355 m field nearly so). The fine detail of the 20 m humidity field missed some precipitation. The position of the front

was accurately forecast, even 18 hours ahead, and a large area of actual rainfall off the east coast of Scotland corresponded with an area of greater than 95 % relative humidity at 355 and 810 m. The disenhanced fields for 355 m and 810 m are very similar, both showing some quite large areas of over-disenhancement.

2.3.5 09NOV92 1000 VT: 06 model run (T+4)

This was a day when extensive orographic enhancement was likely. The model did not predict a double band of rain that had developed by the verification time. The most plausible humidity field to use was at 810 m. Over-disenhancement was minimal at all levels studied. The screen humidity was in the main part similar to the 20 m humidity over the UK.

2.3.6 30NOV92 0000 VT: 06 model run (29NOV92 T+18)

The 810 m humidity field best followed the distribution of actual rain. The highest orographic rainfall was found in Cornwall, S Wales and NW Wales. The amount of over-disenhancement was the same for 810 and 355 m humidity levels.

2.3.7 30NOV92 1200 VT: 06 model run (T+6)

Orographic rain was heaviest in W Scotland, S and NW Wales. The 810 m field was the best humidity field to use, the high humidity areas covering all actual rainfall except for small areas west of the Outer Hebrides and west of Ireland. The boundary delineating humidities of less than 85 % covering NE Scotland tied in especially well with the actual rainfall image. The amount of over-disenhancement is very low at all levels.

3 Comparison of model and actual data

3.1 Comparison of sonde and model data

It was not intended that this study would include an evaluation of the accuracy of the mesoscale model. However, as a rough check, humidities at the 20, 355 and 810 m levels were determined from sonde ascents and compared with model relative humidities. Assuming an air density of 1.2 kg m^{-3}, and knowing the station surface pressure, the pressure at height h (20, 355 or 810 m) was calculated using the hydrostatic equation. Using the calculated pressure, the relative humidity was then determined from the t-ϕ diagram.

Table 1 shows the calculated relative humidities and model humidities for 09NOV92 1200 hrs. The biggest discrepancy is at Stornoway at 810 m, but this may be excused due to the proximity of the boundary defined by the model relative humidity threshold of 85 %, and also due to the proximity of the station to the front that has just passed through. The figures from Valentia clearly show the dry air behind the front. Generally, though, the two values of relative humidity are in close agreement at 355 m and 810 m, usually within $\pm$ 5 %. Data at 20 m are not so well correlated. Table 2 shows the data from a similar analysis of data from 12MAY92 0000 hrs. The favorable comparisons at 355 and 810 m affirms confidence in the model humidity fields.

3.2 Comparison of model with surface actual data

As a check on model accuracy, the comparison can be made between the model 20 m relative humidity and the observed screen-level relative humidity. Figure 11 shows the screen humidity for 03JUL92 1000 hrs, data extracted from the Synoptic Data Bank (SDB) and interpolated between stations. A comparison with Figure 8, the 20 m relative humidity field at the model verification time, shows that the model has accurately mapped out the important 85 % boundary over Scotland and the east coast of England. This is one of the best comparison cases, but generally the match is good. Although the 20 m relative humidity field is unlikely to be used in any forecast scheme, this does reinforce confidence in the model to accurately predict humidity fields.

4 Summary of results

The best comparison between humidity field and areas of orographic correction is hard to limit to a single humidity level. Nevertheless, the 20 m level can be excluded as a candidate as it is too restrictive (missing too much actual rain, and therefore some enhancement), and is too easily modified by surface effects to be used in a correction scheme. The 355 m level also misses some enhancement. Therefore, the best choice for a relative humidity level appears to be 810 m, the level which best encompasses the areas where orographic enhancement is thought to be occurring. Spurious enhancement was not apparent.

Minimising the amount of 'negative rain' in the disenhanced image was used as an empirical criteria for chosing between between full orographic correction and use of a humidity factor.

It was found that by using a humidity factor the amount of 'drop out' (negative rainfall) encountered was not increased to unacceptable levels in disenhanced radar images, and was actually reduced in some images, as well as on all images using the 20 m level model data (although this was mostly due to lower relative humidities at the lower level: see below).

Additionally, the model 20 m relative humidity field produced fewer negative values than the 355 m relative humidity field, which in turn produced less than the 810 m relative humidity field. This is hardly surprising as the degree of disenhancement is partially dependant in the relative humidity which tends to be lower at 20 m than at 810 m.

5 Over-correction and disenhancement

The problem of over-correcting the orographic enhancement so that the disenhanced rainfall is negative has three possible causes; (a) the base orographic correction is too large; (b) the percentage seen value is too large; (c) the relative humidity value is too large, or (d) unavoidable random errors. Possibly the over-correction is due to a combination of factors. The orographic correction tables are least likely to be the source of the error as they have been most tested. As the model winds are likely to be more accurate than the model humidities, selection of the orographic tables is probably sound.

A steady decrease in disenhanced value as the orographic correction multiplied by the percentage seen increased would be evidence of the application of systematically over-corrected orographic enhancements; the bigger the correction, the lower the background rainfall rate, a relationship

that could not be meteorological in nature. In an attempt to determine the main cause of the over-disenhancement (percentage seen x orographic enhancement, or humidity correction factor), such plots were made of the fraction seen of orographic enhancement multiplied by the orographic correction against the disenhanced rainfall rate.

Figure 12 shows data for an area covering the whole of Wales at 09NOV92 0000 hrs, using the model humidity field at 810 m. Data are shown for both full orographic correction and humidity correction factor methods. Percentage seen values are equal to or greater than 60 %, a threshold chosen to confine the selected pixels to ranges close to the radars (most pixels are in the vicinity of the Dyfed radar). Setting a threshold served two purposes. Firstly, this ensured that spurious rainfall figures due to bright band effects were eliminated, as the radar beams would not yet have intercepted the levels close to the freezing level where the bright band effect occurs, a problem encountered when the percentage-seen threshold was initially set to 30 %. Secondly, it was hoped that by limiting the range of percentage-seen values the full effect of using the humidity correction factor could be observed, as estimates of percentage-seen are likely to be most accurate close to the radars.

Figure 12 illustrates the influence of the humidity correction factor on calculated orographic corrections. The data processed using the humidity factor are shown, as are the data using the full orographic correction for humidities greater than 85 %. The trend is unmistakable. Using the humidity factor leads to bigger orographic corrections, and a greater amount of over- disenhancement. However, the humidities for these data are all over 98 %, leading, for every pixel, to a humidity factor (by which the orographic table value is multiplied) of greater than 1.3. Nevertheless, it can be seen that the negative values are small, in absolute terms, indicating that the orographic enhancement seen is not greatly overestimated.

It should be noted that the large proportion of pixels with a negative disenhancement is a result of selecting a high percentage-seen threshold. With a threshold of 30 %, only 36 of 247 pixels were negatively disenhanced.

The main conclusion from Fig. 12 is that the humidity factor should not be allowed to exceed unity. The orographic corrections subtracted seem too large, which may be due to a problem in the basic enhancement tables or the formulation of the percentage seen. Regarding the former, it may be that the model is selecting the next highest wind catagory for some pixels due to measuring errors, tipping borderline cases into a higher catagory. This may also happen with wind directions. Further work is necessary to determine if the error is consistant, or limited to this case.

6 Conclusions

1. For cases of widespread frontal rain, this scheme, using a humidity scale factor in conjunction with mesoscale model wind and relative humidity fields and raw radar data, was proficient in automatically selecting areas of orographic rainfall.

2. Mesoscale model humidity fields were compared with sonde ascent data. The model forecast data and sonde actual data compared well (usually within $\pm$ 5 %) at levels of approximately 355 m and 810 m. Correlations were not as good with 20 m sonde data. One reason may be that most sonde sites are coastal and may be in model 'sea' grid squares. The model data

compared well with surface observations restored from the SDB.

3. The 355 m and 810 m relative humidity fields generally reflect the trend of increasing relative humidity with height. Generally, the amounts and extent of orographic rain as calculated using these two humidity fields are very similar. However, using the $\geq$ 85 % relative humidity field to determine where precipitation was possible, the 810 m field in every case covered the areas of frontal rainfall as seen in the raw radar image. It is suggested that the 810 m relative humidity model field is used in conjunction with the 810 m model wind fields in the orographic enhancement calculation scheme.

4. The mesoscale model 20 m relative humidity field is heavily influenced by surface conditions (especially over the sea) and as such should not be used in the correction scheme.

5. At the chosen level of 810 m, the cases of negative disenhancement with a humidity factor were slightly more numerous than those cases using the full orographic correction. However, the humidity factor model seems more realistic, and the differences at high RH values are very small. It was not possible to test the humidity factor method at RHs close to 85 %. When it occurs, the amount of negative disenhancement is small, in absolute terms, indicating that the corrections are of the right magnitude.

6. Evaluation of the disenhancement field is sensitive to bright band effects. Further analysis of the calculation of the disenhanced field should be left until after the bright band corrections have been applied to the raw rainfall data. In the final radar algorithm, the bright band corrections will be applied to the raw data before enhanced and disenhanced rainfall fields are calculated.

7 Further development and implementation in Nimrod

7.1 Further work

While this scheme is at least favourably comparable with the 'manual' scheme it will replace, further study is necessary to determine the accuracy of the calculations of amount of orographic rain. This is a very large task which possibly would involve calculating again Hill's orographic enhancement tables and the percentage enhancement seen tables for areas close to the radars. Interim work would best be confined to tuning of the humidity factor algorithm. For example, orographic corrections may be improved by using a humidity factor no greater than 1, or by applying some threshold limit to the disenhanced rainfall rate, beneath which no orographic enhancement can occur (as the seeder rainfall rate is too small).

7.2 Combination with range and bright-band correction schemes

Work is in progress to integrate the orographic correction software into the range and bright-band correction software, and run the scheme for a number of test cases. The software required for this operation will be described in a later technical note.

8 Appendix: Data restoration and processing

Restoring mesoscale model archive data

Data is restored from the mesoscale model archive on COSMOS using software on COSMOS and MUPPET. Data is restored as follows:

1. On COSMOS, edit a copy of IBMA::MS24.DA1.CNTL(RESTORE) to restore the required day and hours of data. Output is of the form DAFChh.VBS (unformatted dataset) and DAFChh.DA (formatted dataset from which fields are extracted), where hh is the hour restored. A full description of RESTORE is found in "A Method of Obtaining Mesoscale Model Data for Case Studies", Nowcasting Development Group Working Paper No.32, by J.A.Pamment.

2. On COSMOS, edit a copy of IBMA::MS24.DA1.CNTL(ACCESS2) to extract cloud base files. Run ACCESS1 to recompile ACCESS2. Run ACCESS2. Output is of the form HhhZ.CLDBAS.

3. On COSMOS, edit a copy of IBMA::MS24.DA1.CNTL(MHUMID) to extract humidity and winds data. Output is of the form HhhZ.MMRELHUM.

4. On MUPPET, copy files to MUPPET using the convention;

```
From        IBMA::[MS24]HhhZ.MMRELHUM
To          MUPPET::[FRONTIERS.HUMIDS]ddmmmyy_HUMID_HhhZ.llllDAT
```

   for humidity/wind fields, where ddmmmyy is the date, hh is the hour and llll is the height of the humidity level, and for cloud base files, use

```
From        IBMA::[MS24]HhhZ.CLDBAS
To          MUPPET::[FRONTIERS.HUMIDS]ddmmmyy_CLOUD_HhhZ.llllDAT
```

5. The data is then transferred from the mesoscale grid (89 x 91) to the FRONTIERS grid (256 x 256) using

```
humidities/winds    program    [FRONTIERS.HUMIDS]NEW_MM_HUMIDITY
                    output     [FRONTIERS.HUMIDS]HUMIDITY_FIELD_HhhZ_llll.INT

cloud base          program    [FRONTIERS.HUMIDS]CLOUD_BASE
                    output     [FRONTIERS.HUMIDS]CLOUDBASE_FIELD_HhhZ.INT
```

6. These fields are then copied to HAMLET::[FRONTIERS.MAIN.HUMIDS.PARK]. Note that any files with the same hour will be overwritten.

Software for processing data and displaying images

Unless otherwise stated, processing software is found on HAMLET::[FRONTIERS.OROG]. Restoration of raw radar data is as follows:

1. Restore raw data to disk from magnetic tape using [ZUSERDATA]TAPE_RESTORE.COM, or from DAT cartridge using DAT_RESTORE.COM. The COM file has to be edited so data is restored for the correct day and times.
2. Program RAW composites the raw radar data and percentage seen fields.
3. Program OROG_RAIN produces the orographic corrections (using restored mesoscale model relative humidity fields and winds), applies corrections to the radar data to produce the enhanced image, calculates the orographic area, and disenhanced image, and outputs data to disk.
4. Images can be displayed using the program IMAGE_DISPLAY.

Output images

The processing software produces the following output fields for display:

1. Orographic areas- shows where orographic enhancement can occur on the basis of model 810 m wind velocity and relative humidity fields. The 810 m winds have to be great enough, and the air humid enough, for a pixel to be classified as being in an orographic area.
2. Raw radar images: produced for the whole of the UK, a composite of individual radar images.
3. Percentage seen: the fraction of orographic enhancement seen. This mostly depends upon the distance of the pixel from the radar site.
4. Enhanced image: base image plus the proportion of the calculated orographic enhancement not seen by the radar.
5. Disenhanced image: base image minus the "seen" enhancement. Pixels over-corrected appear as black pixels on the reversed-image printout of the disenhanced field, appearing as the highest value in the display key.
6. Orographic rainfall: these are the areas and amounts of orographic rain.
7. Humidity field: three model levels are looked at; 20 m, 355 m and 810 m.
8. Cloud base: as the mesoscale model cloud base field is partially derived from the humidity fields, this field in part fills in some information about humidities at other levels in the model. The cloud base field is useful in some cases to determine frontal boundaries.

9 References

Bergeron T. (1965) On the low-level redistribution of atmospheric water caused by orography. Suppl.,Proc.Int.Conf. on Cloud Physics, Tokyo 1965, 96-100.

Brown R. and Sargent G.P. (1987) The calculation of the percentage of orographic enhancement seen tables. Nowcasting research Group Report no. 11. Met. Office, Bracknell. Unpublished.

Hill F.F. (1983) The use of average annual rainfall to derive estimates of orographic enhancement of frontal rain over England and Wales for different wind directions. J.Climat., 3, 113-129.

Hill F.F. (1981) Mean fields of orographic rainfall enhancement over England and Wales for different wind directions and their application to short-period forecasting. Met. Office Radar Research Lab. Research Report no.26 Unpublished.

Hill F.F., K.A.Browning and M.J. Bader (1981) Radar and rain-gauge observations of orographic rain over South Wales. Quart. J.R.Met.Soc., 107, 643-670.

Sargent G.P. (1992) Automatic Orographic Enhancement: A Preliminary Report. S-Division Working Paper no.53. Met Office, Bracknell. Unpublished.

10 Tables and Figures

List of Tables

1. Comparison of model and ascent-derived relative humidities 09NOV92 1200Z. Lerwick model relative humidities are inferred.

2. Comparison of model and ascent-derived relative humidities 12MAY92 0000Z. Lerwick model relative humidities are inferred.

List of Figures

1. Disenhanced image for 24APR92 1100 hrs. The relative humidity (RH) field is taken from the T+5 forecast from the 06 model run, and is at a model level of 810 m. An orographic correction factor is used, multiplying the orographic correction linearly from 0 at an RH of 85 % to 1.5 at an RH of 100 %. The disenhanced image is produced by subtracting the amount of orographic enhancement seen from the base image. Where the resulting value is negative (ie, too much enhancement has been removed), the pixel appears black. This is a feature of the display program; there are no UK orographic enhancements of greater than 32 mm hr^{-1}.

2. As Figure 1, but the full orographic enhancement from the orographic tables is applied for RH greater than 85 %. In this particular case, the number of negative pixels is slightly higher when the humidity factor is used (Fig. 1).

3. Relative humidity (RH) field as restored from the mesoscale model archive, for 24APR92 1100 hrs, for a model level of 810 m. The blue and yellow areas represent RHs greater than 85 %, a value above which orographic enhancement can occur.

4. Disenhanced image for 24APR92 1100 hrs. The relative humidity (RH) field is taken from the T+5 forecast from the 06 model run, and is at a model level of 20 m. The humidity scale factor is used. Note that there are fewer negative (over-disenhanced) pixels than when using 810 m RHs, due to lower relative humidity values at 20 m.

5. Relative humidity (RH) field as restored from the mesoscale model archive, for 24APR92 1100 hrs, for a model level of 20 m, quite different to that at 810 m (Fig. 3).

6. Cloud base field for 24APR92 1100 hrs, from the mesoscale model 06 run, T+5 forecast. Unlike the humidity data, the original 15 km resolution has been preserved. The band of low cloud (green and yellow) is along a cold front, and is the source of most of the precipitation. Behind the front, over Northern Ireland, the rainfall is convective, from clouds with a high cloud base.

7. Orographic rain field for 03JUL92 1000 hrs. Image produced using the 810 m RH and wind fields from the T+5 forecast (06 model run), and the humidity factor.

8. 20 m RH field (T+5 forecast, 06 model run) for 03JUL92 1000 hrs. As the wind velocities at 810 m are great enough for an orographic table to be selected at every pixel, the humidity field boundary between $>$ 85 % RH (shades of blue and yellow) and $\leq$ 85 % (green) also defines

the orographic area, the area where orographic enhancement could theoretically occur. This is the non-green area over the UK. Comparison with the raw radar image shows that some orographic enhancement produced using the 810 m RH field is missed by the 20 m orographic area.

9. 810 m RH field (T+5 forecast, 06 model run) for 03JUL92 1000 hrs. The orographic area covers a larger area than the 20 m field. This is the most important reason for choosing the 810 m RH field over the 20 m RH field in the correction scheme; minimising the chances of missing orographic enhancement.

10. Disenhanced image for 11MAY92 2100 hrs. The 810 m RH field was used, as was the humidity factor. The over-disenhanced (black) areas are actually areas of quite low rainfall rates.

11. Screen relative humidity for 03JUL92 1000 hrs. This field is produced from data restored from the Synoptic Data Base (SDB) and interpolated between stations. Software by M.Kitchen (Met O FR). Comparison with the 20 m humidity field (Fig. 8) shows how closely the important 85 % humidity boundary has been modelled.

12. Fraction of enhancement seen x orographic correction against disenhanced rainfall rate, for rain pixels over Wales on 09NOV92, at 1000 hrs. Most pixels in the radar composite are imaged from Dyfed. To observe what happens close to the radar, only pixels with a percentage seen of 60 % or greater were selected. It can be seen that the degree of disenhancement is small. The figure shows data processed using the humidity scale factor (circles) and also applying full orographic corrections (filled in circles). The calculated humidity correction factor (HCF) is greater than 1.3 for all of these points, as the relative humidity is greater than 98 %. The use of the HCF has slightly increased disenhancement; the values are still small. Correlations excluding a single point higher than 40 mm hr^{-1} (possible bright band) are as follows: for the HCF case the correlation coefficient is -0.677, and the best fit line is of the form $y = -0.911x + 0.662$. For the full correction dataset the correlation coefficient is 0.585. The best fit line is $y = -0.860x + 0.651$.

Table 1

Comparison of model and ascent relative humidities 09NOV92 1200Z (model T+6)			
Boulmer	mslp 1002.7		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	999.6	85-90	88
335	960.2	95-100	89
810	906.7	90-95	92
Herstmonceux	mslp 1013.6		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	1010.6	85-90	-
355	971.2	95-100	93
810	917.7	95-100	97
Larkhill	mslp 1010.3		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	1007.6	90-95	-
355	968.2	95-100	> 99
810	914.7	95-100	99
Lerwick	mslp 995.8		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	993.4	90-95?	-
355	954.0	95-100?	87
810	900.5	95-100?	92
Long Kesh	mslp 1002.0		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	999.6	85-90	97
355	960.2	90-95	89
810	906.7	95-100	86
Stornoway	mslp 998.2		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	995.8	< 85	84
355	956.4	< 85	75
810	902.9	90-95	69
Valentia	mslp 1007.0		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	1004.6	< 85	83
355	965.2	< 85	79
810	911.7	< 85	82

Table 2

Comparison of model and ascent relative humidities 12MAY92 0000Z (model T+18)			
Boulmer	mslp 1002.6		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	999.6	85-90	78
335	960.2	85-95	80
810	906.7	95-100	89
Camborne	mslp 1016.0		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	1013.6	85-90	95+
355	974.2	95-100	93
810	920.7	95-100	90
Hemsby	mslp 1016.0		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	1013.6	85-90	82
355	974.2	95-100	71
810	920.7	85-90	45
Lerwick	mslp 999.0		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	996.6	<85-90?	85
355	960.2	90-95?	91
810	906.7	95-100?	93
Long Kesh	mslp 1000.4		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	997.6	85-90	89
355	958.2	90-95	97
810	904.7	95-100	100
Stornoway	mslp 992.8		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	990.1	< 85	76
355	950.7	< 85	77
810	904.7	85-90	79
Valentia	mslp 1006.0		
height (m)	pressure (mb)	relative humidity model (%)	relative humidity ascent (%)
20	1003.6	90-95	96
355	964.2	95-100	96
810	910.7	95-100	97

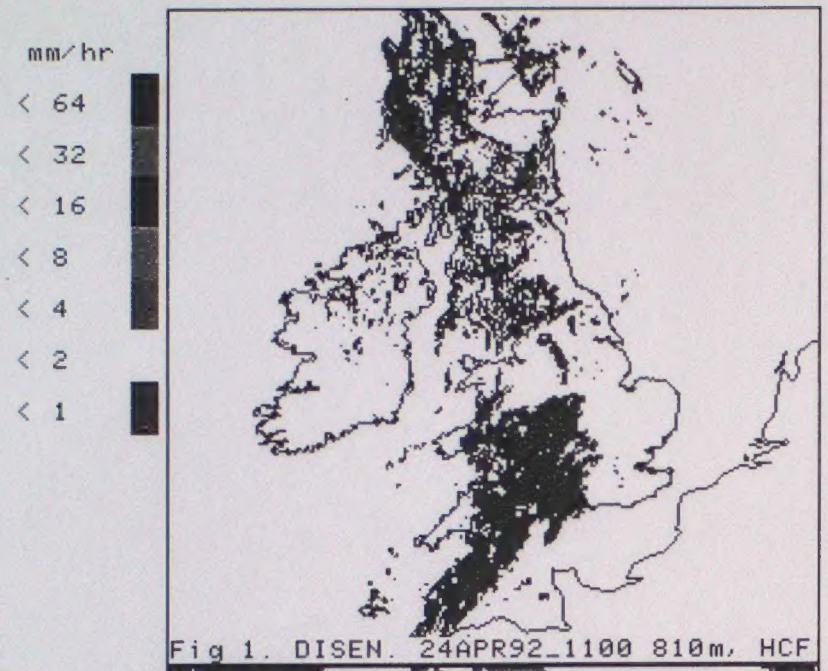

Fig 1. DISEN. 24APR92_1100 810m, HCF

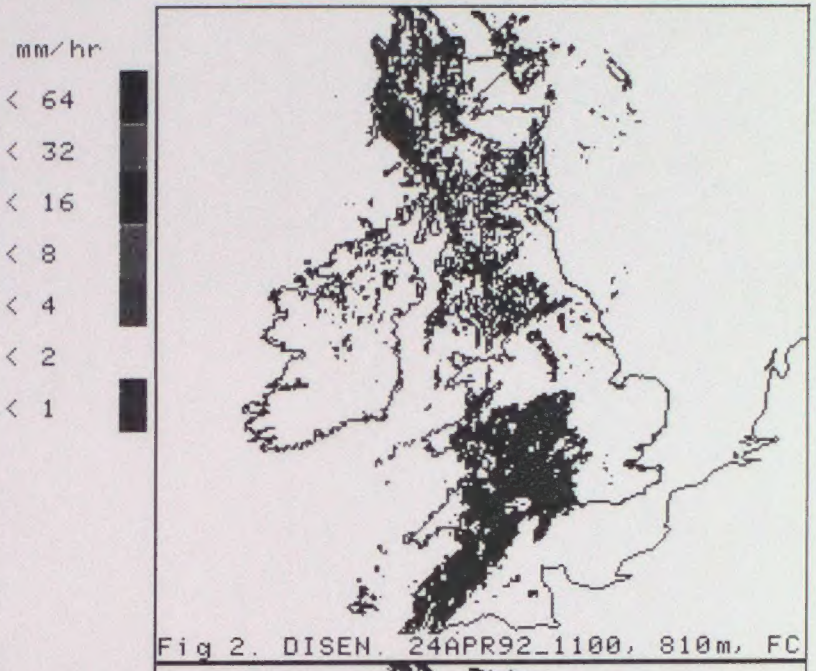

Fig 2. DISEN. 24APR92_1100, 810m, FC

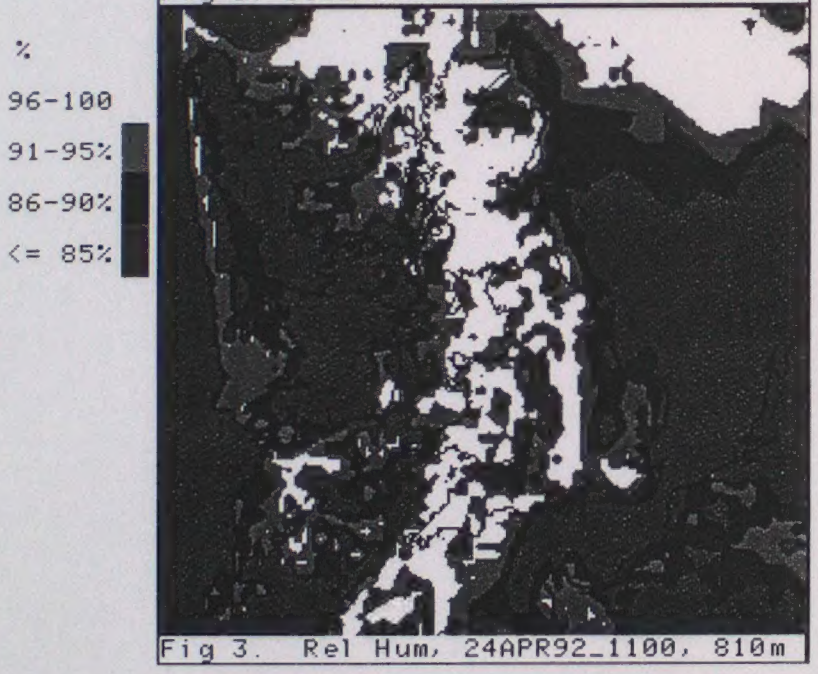

Fig 3. Rel Hum, 24APR92_1100, 810m

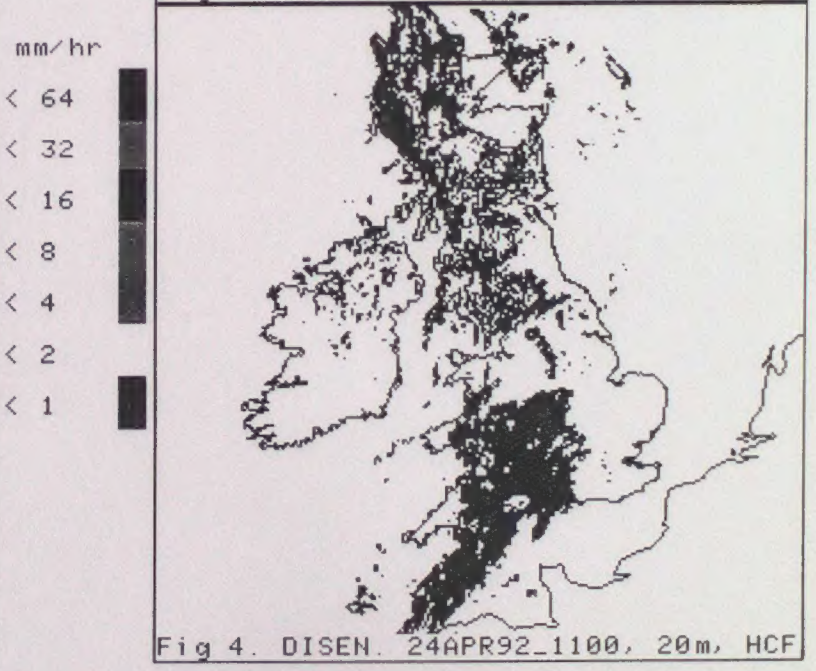

Fig 4. DISEN. 24APR92_1100, 20m, HCF

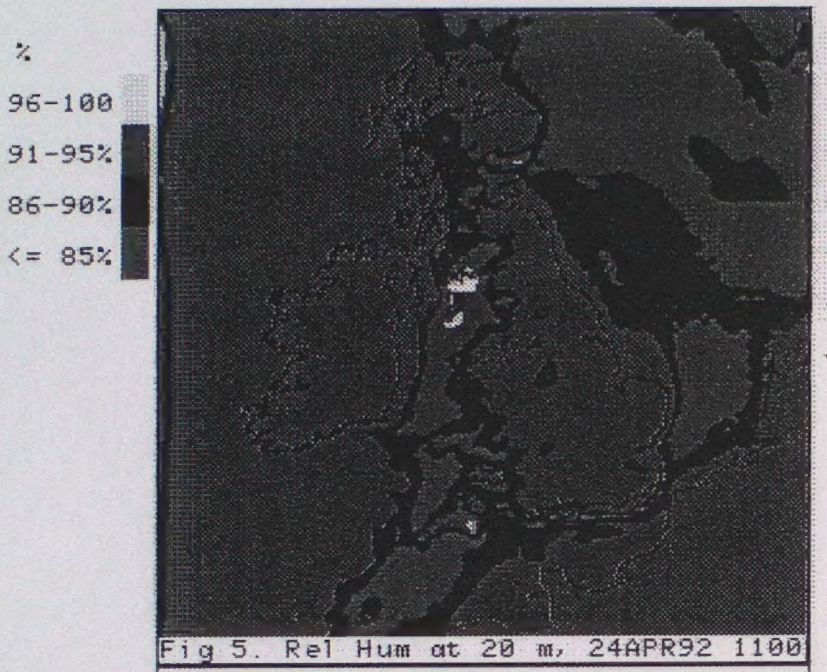

Fig 5. Rel Hum at 20 m, 24APR92 1100

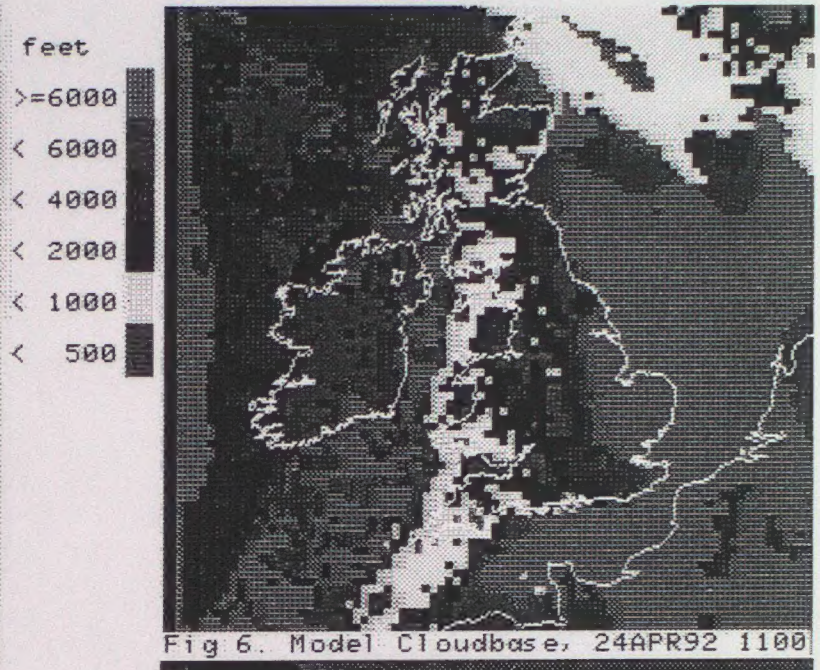

Fig 6. Model Cloudbase, 24APR92 1100

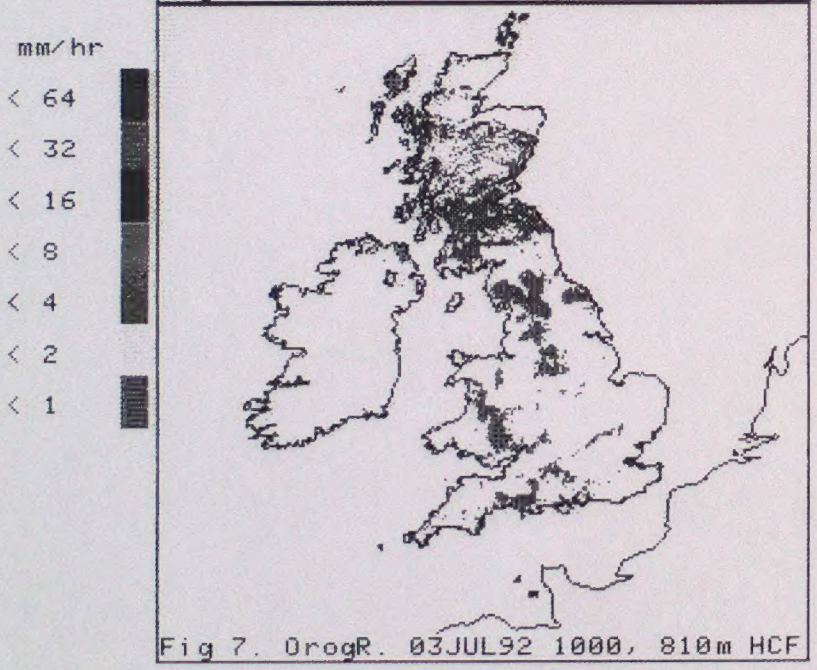

Fig 7. OrogR. 03JUL92 1000, 810m HCF

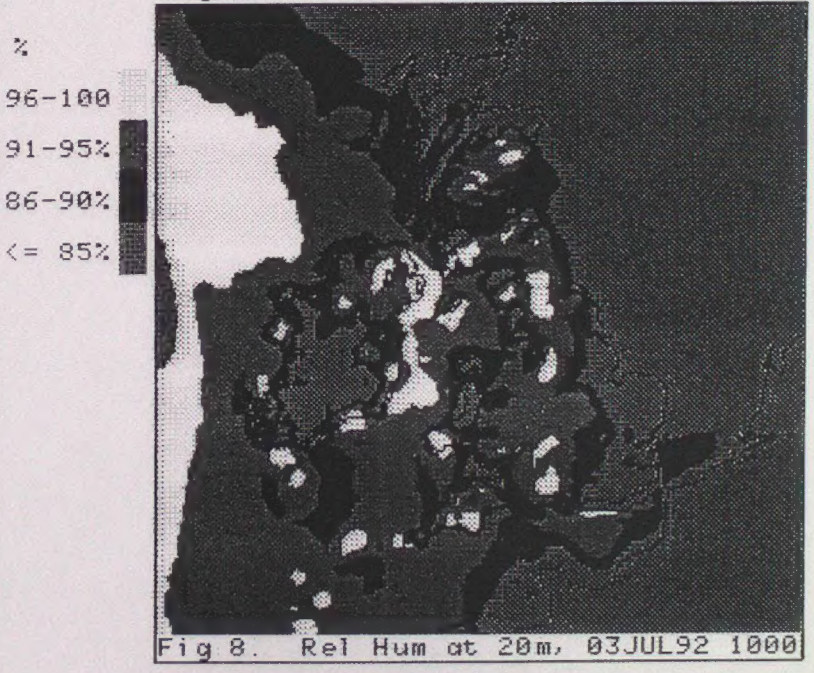

Fig 8. Rel Hum at 20m, 03JUL92 1000

%

96-100

91-95%

86-90%

<= 85%

Fig 9. Rel Hum at 810m, 03JUL92 1000

mm/hr

< 64

< 32

< 16

< 8

< 4

< 2

< 1

Fig 10. Disen. 11MAY92 2100 810m HCF

96-100

91-95%

86-90%

<= 85%

Fig 11. Screen RH, 03JUL92 1000.

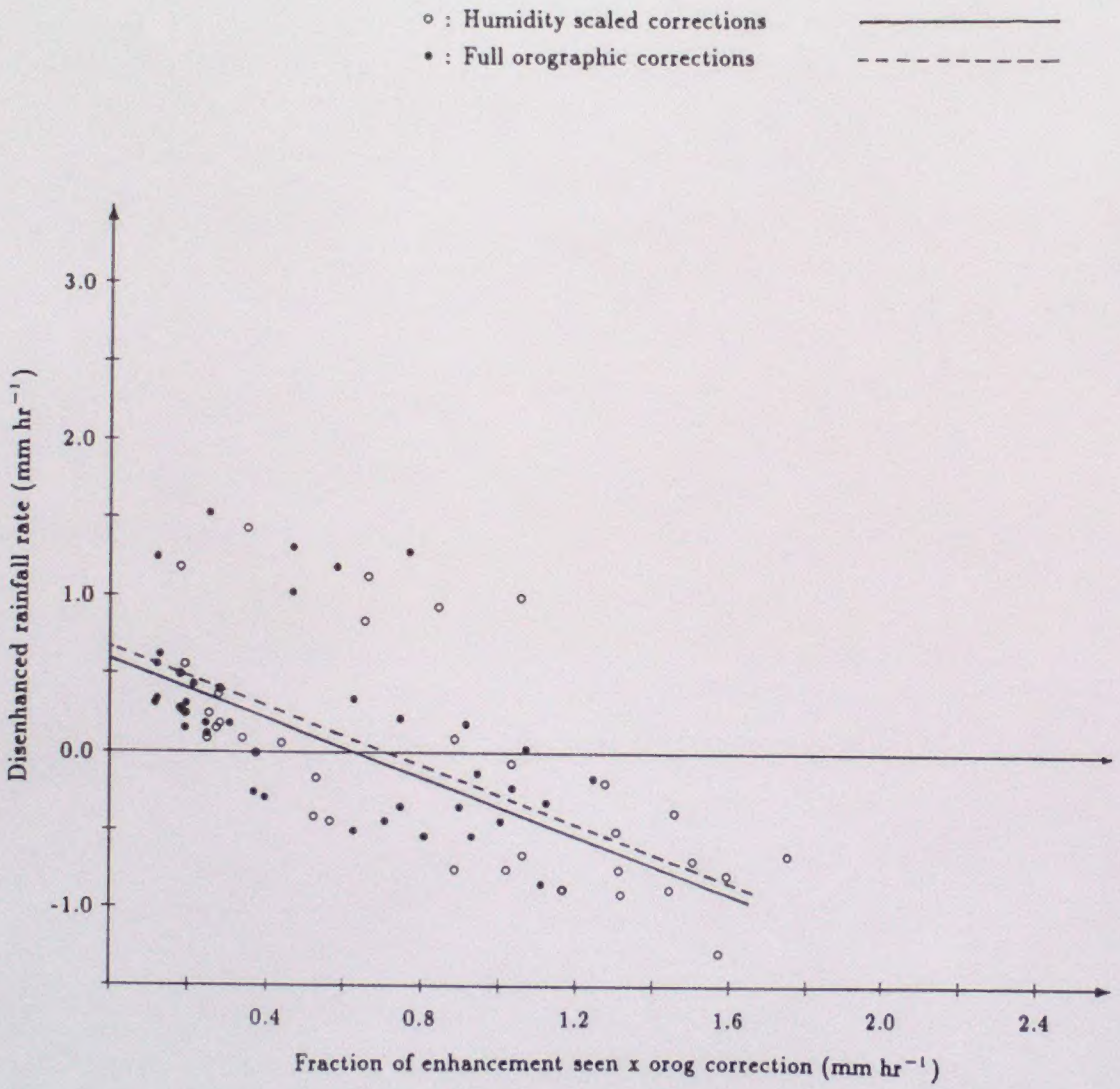

Figure 12: Comparison of correction methods.
Data for Wales, 09NOV92 1000 hrs. 810 m RH, %-seen threshold $\geq$ 60 %.